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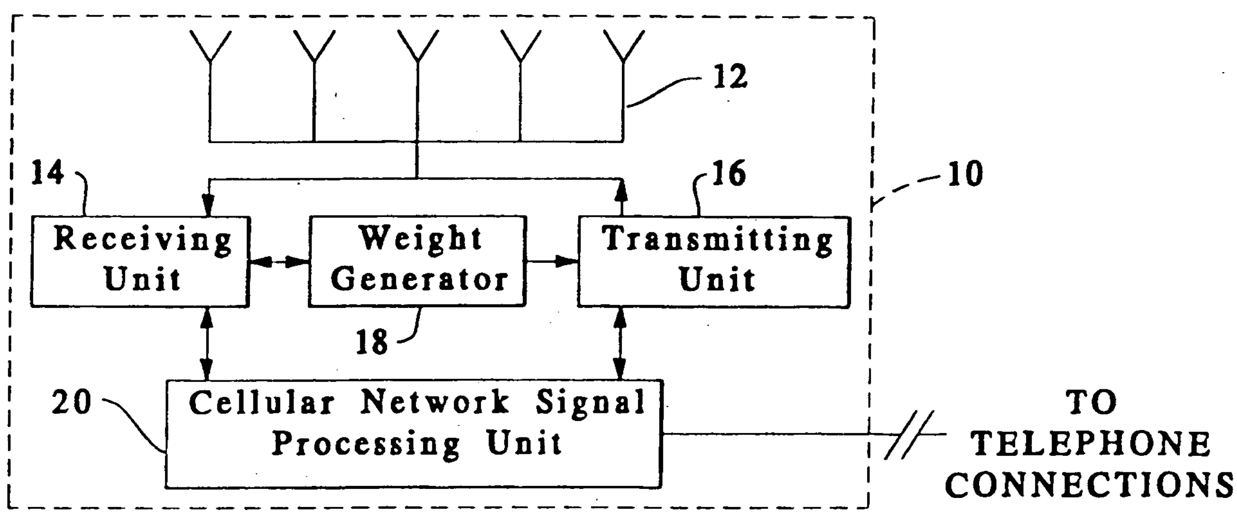

(57) Abstract

A cellular telephone base station (10) uses spatial signal processing to null co-channel (same frequency) interference, such as interference caused by other co-channel radio transmitters and multipath. Radio beams are formed by an antenna array (12) for either or both the transmit and the receive portions of the communications link. Amplitude and phase weighting is applied to inphase and quadrature (I&Q) channels of an array of antenna elements. For the receive portion of the link the weighted signals from these antenna channels are summed to produce a beamsummer output. For the transmit portion of the link the outgoing I&Q signal is amplitude and phase weighted, and then transmitted by the antenna elements in an array to form spatial beams. Antenna array weights are dynamically updated as the angled of arrival of the received signal changes.

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ADAPTIVE CO-CHANNEL INTERFERENCE REDUCTION SYSTEM FOR CELLULAR TELEPHONE CENTRAL BASE STATIONS

BACKGROUND OF THE INVENTION

The present invention is directed to a novel method and system for reducing co-channel interference in cellular telephone systems. More particularly, it is directed to a novel method and system for automatically adapting the spatial gain pattern of an antenna array in a cellular telephone base station to optimize the signal to interference plus noise ratio in the communication links between the base station and the cellular telephone of interest.

To meet the demands of a large user population, modern cellular telephone systems include a network of cells which service communications traffic in their respective areas of coverage. Each cell includes a fixed site base station that uses radio frequency (RF) signals to communicate with cellular telephones on a number of different narrowband frequencies (i.e., channels). The base stations are desirably located so that a user is always within radio range of a base station, although geological or manmade obstructions may inhibit clear communications.

Such cellular systems are not without problems. For example, when two or more telephones assigned to the same channel are located in a region of overlapping cell coverage, the RF signals for one of the telephones may be corrupted by co-channel interference caused by the other telephones operating on the same channel. The RF signals may also be corrupted by co-channel interference caused by multipath that can distort the FM portion of the signal.

Prior art cellular systems have had limited success dealing with co-channel interference. Cellular systems in high user-density areas use multiple antennae to take advantage of antenna directivity. Individual antennae are pointed in different directions so that their individual beams collectively cover the cell area. An electronic voting method is used in which each cellular telephone is assigned to the antenna which has the largest signal to noise ratio (SNR). However, the balancing of antenna beam width, coverage area size and number of antennae that takes place during the design of cellular systems often results in wide beams that remain susceptible to co-channel interference. In other words, the antennae in use are not directive enough to eliminate co-channel interference, and the cost of providing the requisite number of sufficiently directive antennae is often prohibitive.

In contrast, the base station of the present invention uses multiple antennae that are joined to form an adaptive antenna array in which all antennae are used collectively to establish a single highly directive beam for each channel that all but eliminates co-channel interference. The beam is adaptively directed toward the cellular telephone of interest and moves as the telephone moves.

Adaptive antenna arrays are known generally. See, for example, U.S. Patent No. 4,800,390 to Searle. However, and despite the many significant advantages the use thereof would have provided, they have not been applied to cellular telephone systems, and more particularly to base stations for cellular telephone systems to simultaneously form single channel directional beams for each of the radio links with the plurality of cellular telephones.

Accordingly, it is an object of the present invention to provide a novel method and system that obviate the problems of the prior art and improve cellular telephone communications by using an adaptive antenna array.

It is another object of the present invention to provide a novel method and system that adaptively form highly directional gain patterns for the transmit and/or receive portions of the communications links of cellular telephone system base stations.

It is yet another object of the present invention to provide a novel method and system for using an adaptive array in cellular telephone communications links wherein all antennae are used simultaneously to form array beams for each channel so that co-channel interference is reduced or eliminated.

It is a further object of the present invention to provide a novel method and system for using an adaptive array wherein all antennae are used simultaneously to form array beams to increase the signal to interference plus noise ratio of a signal for a target telephone.

These and many other objects and advantages of the present invention will be readily apparent to one skilled in the art to which the invention pertains from a perusal of the claims, the appended drawings, and the following detailed description of preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of a cellular telephone base station of the present invention.

Figure 2 is a schematic diagram illustrating an embodiment of the receiving unit of the present invention.

Figure 3 is a block diagram illustrating receive weight factor processing in the embodiment of Figure 2.

Figure 4 is a schematic diagram illustrating an embodiment of the transmitting unit of the present invention.

Figure 5 is a block diagram illustrating transmit weight factor processing in the embodiment of Figure 4.

Figure 6 is a block diagram of an embodiment of the contiguous frequency band assignment circuit for the transmitting unit of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention may be implemented at RF, IF, and/or baseband, and with analog and/or digital signal processing. The description that follows is an example of implementation at IF with digital signal processing, with other embodiments being determinable by those skilled in the art from perusal hereof.

With reference now to the figures where like elements of the present invention have been given like numerical designations to facilitate an understanding thereof, and with particular reference to Figure 1, the present invention may be implemented in a base station 10 of a cellular telephone

system. The base station 10 may include an antenna array 12 for receiving and/or transmitting RF signals, a receiving unit 14 for receiving an processing RF signals, a transmitting unit 16 for processing and transmitting RF signals, a weight generator 18 for providing weighting coefficients to the receiving unit 14 and transmitting unit 16 that are used to adaptively form beams at the antenna array 12, and cellular network signal processing unit 20. The signal processing unit 20 links the base station 10 to telephone central offices and other telephone connection systems so that cellular telephone calls may be routed as required. The antenna array 12 and the cellular network signal processing unit 20 may be of known design and operation. The receiving unit 14, transmitting unit 16 and weight generator 18 are discussed in more detail below.

With reference now to Figure 2, an embodiment of the receiving unit 14 of the present invention may be seen. Received radio plane waves impinge on the antenna array 12 that may include multiple antennae 22. The antennae 22 may be arranged so that the distance between adjacent antennae is no further than one half wavelength of the highest radio frequency. The signals received by each of the antennae 22 are passed to a front-end processors 24 which may include

preselectors, downconverters, IF stages, analog to digital converters, formation of I&Q, and frequency domain filtering which separate the individual cellular telephone signals into separate frequency bands. For ease of understanding, only one frequency band signal flow path for each antenna is shown in full in Figure 2.

As shown in Figure 2, the output of the processor 24 for each antenna 22 is a set 26 of separated frequency bands, each output consisting of I&Q components corresponding to the particular frequency for a cellular telephone channel. The outputs of processor 24 are passed to signal dividers 28 which split the I&Q signal of each frequency band into two outputs, each identical to the input.

One output of each signal divider 28 is provided to the weight generator 18 and the other output of each signal divider 28 is provided to a receive weight structure 30. As will be discussed in more detail below, receive weight factors 32 are computed in weight generator 18 in response to the relative value of the received signal from the telephone of interest and are provided to the receive weight structure 30. The output 34 from the receive weight structure 30, discussed in more detail below, is passed to a beamsummer 36 which adds the complex I&Q signals for each frequency band to produce a

signal in which the target cellular telephone signal is contained with co-channel interference attenuated, i.e., an output signal for which the signal to interference plus noise ratio is enhanced.

The operation of receive weight structure 30 may be more easily seen with reference to Figure 3. The weight structure 30 modifies the amplitude and phase of the I&Q signal from the signal divider 28 with the receive weight factors 32 from the weight generator 18. The receive weight factors 32 are coefficients that are updated in real time by the weight generator 18 and multiplied times the input signal to the weight structure 30. Each receive weight factor 32 is a complex weight that is applied as a multiplicand to the complex multiplier stage 38 to modify the gain and phase of the input signal. The output of multiplier 38 is provided to beamsummer 36. As can be appreciated, the target signal is monochromatic because front end processing 24 separates the received cellular telephone signals into separate channels. Because the target signal is monochromatic, only one multiplier is needed in weight structure 30.

With reference now to Figure 4, an embodiment of the transmitting unit 16 may be seen. Preliminary transmit cellular base station processing by the signal processing unit

20 provides outgoing cellular telephone signals that are in separate channels, one for each target cellular telephone. In the following discussion it will be assumed that these outgoing signals are each at baseband represented in I&Q form, although the transmit processing structure could alternatively be implemented in a number of ways, such as frequency separated contiguous IF channels.

As shown in Figure 4, each baseband output is provided to a multiple output signal splitter 40 which has as many output ports as the number of antennae 22 and which provides output signals 42 that are identical to the input to splitter 40. The outputs 42 of each splitter 40 are provided to transmit weight structures 44 associated with each of the antennae 22. As will be discussed in more detail below, transmit weight factors 48 are computed in the weight generator 18 in response to the angle of arrival of the corresponding received signal and are provided to transmit weight structures 44. The outputs of transmit weight structures 44 are provided to assignment circuits 50 which frequency translate the baseband outgoing target cellular telephone signals into a contiguous frequency domain broadband spectrum, and then sum the translated signals into one output corresponding to the appropriate antenna channel.

Outputs from the assignment circuits 50 are provided to transmitter output stages 52 which perform traditional transmitter output processing such as conversion of I&Q to real format, digital to analog conversion, final upconversion, filtering, power amplification, and impedance matching. Outputs of transmitter output stages 52 are passed to respective antennae 22 forming the array 12.

The spatial gain pattern of the transmitted signals is such that radio beams are adaptively formed wherein a directional main lobe beam with high gain above isotropic is adaptively steered in the direction of the target cellular telephone while maintaining low side lobe levels in other directions.

The operation of transmit weight structure 44 may be more clearly seen with reference to Figure 5. Transmit weight structure 44 modifies the amplitude and phase of the I&Q transmit signal with transmit weight factors 48 generated by weight generator 18. The transmit weight factors 48 are coefficients that are multiplied times the input signal 46.

As shown in Figure 5, a transmit weight factor 48 is used as a complex multiplicand in a complex multiplier stage 54 to modify the gain and phase of the input signal 46. The output of the multiplier stage 54 is provided to assignment circuit

50. Since, in this exemplary embodiment, the output of signal processing unit 20 is baseband, each stage 44 is processing monochromatic signals. However, as in the receiver, a broadband approach for transmission may be used where the processing circuit 44 of Figure 4 would consist of FIR or IIR filters which perform both frequency domain discrimination and spatial domain filtering simultaneously.

The operation of assignment circuit 50 may be more clearly seen with reference to Figure 6. The assignment circuit 50 heterodynes the various outgoing telephone channels for each antenna so that these channels are contiguously packed in the frequency domain to fill the bandwidth for outgoing telephone transmissions. The embodiment of Figure 6 assumes that the outputs from the signal processing unit 20 are at baseband. Appropriate modifications to the embodiment of Figure 6 for other outputs will be apparent to those skilled in the art.

As illustrated in Figure 6, inputs from transmit weight structures 44 corresponding to various outgoing telephone channels are provided to mixers 56. The mixers 56 multiply

the input signal by a CW signal from input unit 58. The CW signal applies the factor e^{jw_it}, where:

$j = \sqrt{-1}$;

w_i is radian frequency for $i = 1,2,\ldots,N$;

N is the number of antennae; and

t is time (either discrete for digital implementation or continuous for analog implementation).

This CW signal operates as a local oscillator which upconverts the telephone channel to a higher frequency (higher frequency assumed here to be at IF for this embodiment) so that all upconverted frequency bands are contiguous.

Outputs of the mixers 56 are provided to summer 60 which adds the N inputs. The output of summer 60 is provided to a filter 62 which passes the sum and rejects the difference components of mixers 56. The output of filter 62 is provided to transmitter output stages 52.

The weight generator 18 is a processor that computes receive weights 32 and transmit weights 48 by means of adaptive signal processing. Receive weights w_r may be constructed by a variety of means including those indicated below which are reported in Larimore, Treichler "Convergence behavior of the constant modulus algorithm", IEEE ICASSP,

1983, where w_r is defined as the column vector of N receive weights for one monochromatic signal:

$$\mathbf{w}_r(k+1) = \mathbf{w}_r(k) - \mu \mathbf{x}^*(k)\frac{y(k)}{||y(k)||}sgn(||y(k)|| - \delta) \tag{1}$$

$$\mathbf{w}_r(k+1) = \mathbf{w}_r(k) - 2\mu \mathbf{x}^*(k)y(k)sgn(||y(k)||^2 - \delta^2) \tag{2}$$

$$\mathbf{w}_r(k+1) = \mathbf{w}_r(k) - 2\mu \mathbf{x}^*(k)\frac{y(k)}{||y(k)||}(||y(k)||^2 - \delta^2) \tag{3}$$

$$\mathbf{w}_r(k+1) = \mathbf{w}_r(k) - 4\mu \mathbf{x}^*(k)y(k)(||y(k)||^2 - \delta^2) \tag{4}$$

where

$\mathbf{w}_r(k)$ is column vector of receive weights at k^{th} snapshot.

$\mathbf{w}_r(k + 1)$ is column vector of receive weights at $(k + 1)^{th}$ snapshot.

*is complex conjugate.

y(k) is the output of beamformer 36 of Fig. 2.

$\mathbf{x}(k)$ is column vector of received narrowband data at k^{th} snapshot. Note that x(k) is indicated by the set of signals from signal dividers 28 to weight generator 18 in Fig. 2.

μ is convergence step size.

$sgn(\cdot)$ is +1 for $(\cdot) > 0$
$sgn(\cdot)$ is -1 for $(\cdot) < 0$
$sgn(\cdot)$ is 0 for $(\cdot) = 0$

δ is target modulus of y(k).

Transmit weights 48 may also be determined in a number of ways. For example, by defining w_t as the column vector of N transmit weights for one monochromatic signal, shading weights

may be constructed such that a main lobe with high directional array gain above isotropic is steered in the direction of the target cellular telephone of interest while side lobes with low gain are maintained elsewhere. Transmit weights w_t are determined by first estimating the angle of arrival ("AOA") of the target signal. AOA may be constructed by a variety of means including MUSIC reported in Schmidt, "A signal subspace approach to multiple emitter location and spectral estimation", Ph.D. thesis Stanford University, Department of Electrical Engineering and Computer Science, November, 1981 and indicated below:

$$P(\theta) = \frac{1}{\mathbf{a}^H(\theta)\mathbf{E}_N\mathbf{E}_N^H\mathbf{a}(\theta)} \quad (5)$$

where

a(θ) is the steering vector:

$$\mathbf{a}(\theta) = \begin{bmatrix} 1 \\ e^{j2\pi\frac{d_1}{\lambda}\sin\theta} \\ e^{j2\pi\frac{d_2}{\lambda}\sin\theta} \\ \vdots \\ e^{j2\pi\frac{d_{N-1}}{\lambda}\sin\theta} \end{bmatrix} \quad (6)$$

d_i is the distance of the i^{th} antenna to the reference antenna.

λ is wavelength.

θ is azimuth angle.

^{H} denotes complex conjugate transpose.

$\mathbf{E}_N$ is the matrix of noise eigenvectors of the measured spatial covariance matrix.

After the weight generator 18 computes AOA, w_t can be determined by a variety of means including deterministic Dolph-Tshebycheff beamforming reported in Balanis, Antenna Theory, Harper & Row Publishers, Inc., 1982 and indicated below:

$$w_{t_n} = \sum_{q=n}^{M} (-1)^{M-q} (z_0)^{2q-1} \frac{(q+M-2)!(2M-1)}{(q-n)!(q+n-1)!(M-q)!} \quad (7)$$

for even N = 2M elements, and

$$w_{t_n} = \sum_{q=n}^{M+1} (-1)^{M-q+1} (z_0)^{2(q-1)} \frac{(q+M-2)!(2M)}{\varepsilon_n (q-n)!(q+n-2)!(M-q+1)!} \quad (8)$$

for odd N = 2M+1 elements

$n = 1,2,\ldots,M+1$

where

$\epsilon_n = 2$ for $n = 1$

$\epsilon_n = 1$ for $n \neq 1$

z_o is a point $z = z_o$ such that $T_m(z_o) = R_o$.

$T_m(z)$ is the Tschebycheff polynomial of order m.

R_o is dimensionless quantity where the sidelobes are R_o dB below the maximum of the main lobe.

In an alternative embodiment, the present invention may simultaneously receive more than one cellular telephoned signal on one frequency band. As indicated above with reference to Figure 2, there is a beamsummer 36 with an output for each frequency band. Signal divider 28 may have

additional outputs passing signals to additional receive weight structures 30 which in turn pass their outputs to additional beamsummers 36. Simultaneous reception of more than one cellular telephone signal on one frequency band may occur when it is desirable to increase the traffic density of a base station by frequency re-use.

While preferred embodiments of the present invention have been described, it is to be understood that the embodiments described are illustrative only and that the scope of the invention is to be defined solely by the appended claims when accorded a full range of equivalence, many variations and modifications naturally occurring to those skilled in the art from a perusal hereof.

I Claim:

1. A geographically fixed base station for one of a plurality of zones in a plural zone cellular telephone communications system adapted for use by large numbers of highly mobile telephone subscribers on plural channels, each of the channels having a predetermined frequency band, the subscribers moving both within a zone and from zone to zone in areas typically having many significant geological and/or manmade obstructions to clear radio communications, said base station having a signal processor and an antenna which because of the environment and nature of cellular telephone systems often receives plural signals on a channel as a result of imperfect channel assignment and/or hand-off of moving cellular telephone subscribers, multipath and the like resulting in relatively low signal-to-interference-plus-noise ratios, the improvement:

wherein said antenna comprises an array of plural antennae physically separated by no more than one-half wavelength of the channel with the highest frequency, said antennae array forming a plurality of highly directed beams, each of said beams for receiving and/or transmitting signals between the base station and one of a plurality of individual cellular telephone subscribers on a channel; and

wherein said base station signal processor includes: means operatively connected to said antennae array and responsive to the angle of arrival of the signal received on each channel for adaptively directing the beams of the antenna array simultaneously for each of the plural channels as a

function of the angle from which the signals on each channel are received by the antennae array,

whereby the signal-to-interference-plus-noise ratios for each of the plural channels are simultaneously improved.

2. In a cellular telephone base station having multiple antennae for receiving RF signals on plural channels, the improvement comprising the use of the multiple antennae in an adaptive array to increase the signal to interference plus noise ratio of RF signals between the base station and one of a plurality of telephone subscribers on a selected channel in the presence of co-channel interference or multipath, the adaptive array simultaneously forming highly directed beams for communicating with each of the plurality of subscribers.

3. The base station as defined in Claim 2 further comprising a signal processor for providing an angle-of-arrival signal representative of the direction from which an RF signal is received by the multiple array on a selected channel.

4. The base station as defined in Claim 3 further comprising means for forming the beam of the adaptive array for the selected channel as a function of the angle-of-arrival signal, and means for dynamically modifying the direction of the beam of the adaptive array as the angle-of-arrival signal changes.

5. A method of reducing co-channel interference among cellular telephone, radio frequency signals at a multiple antennae, cellular telephone base station comprising the steps of:

(a) providing plural antennae for receiving cellular telephone, radio frequency signals on plural channels, with each channel having a predetermined frequency and each antenna providing an output signal including components on plural channels;

(b) providing a weighting signal representative of weight factors for a selected channel;

(c) providing an angle-of-arrival signal representative of the direction from which a signal is received by the antennae array on a selected channel;

(d) forming the beam of the antennae array for the selected channel by the application of the weighting signal to the selected channel components of the output signals from each of the antennae as a function of the angle-of-arrival signal; and

(e) dynamically modifying the beam of the antennae array as a function of modification of the angle-of-arrival signal.

6. Means for reducing co-channel interference between cellular telephone, radio frequency signals at a multiple antennae, cellular telephone base station comprising:

a plural antennae array for receiving cellular telephone, radio frequency signals on plural channels, with each channel having a predetermined frequency and each antenna in the array providing an output signal including components on plural channels;

means for providing a weighting signal representative of weight factors for a selected channel;

means for providing an angle-of-arrival signal representative of the direction from which a signal is received by the antennae array on said selected channel;

means for forming the beam of the antennae array for said selected channel by the application of said weighting signal to the components of said selected channel in the output signals from each of said antennae as a function of said angle-of-arrival signal; and

means for dynamically modifying the angle-of-arrival signal to thereby dynamically modify the beam of the antennae array for the selected channel.

7. A method of reducing co-channel interference at a cellular telephone base station by using an adaptive phased array of antennae to increase the signal to interference plus noise ratio on cellular telephone radio frequency signals, the method comprising the steps of:

(a) providing plural antennae for cellular telephone radio frequency signals having predetermined frequencies;

(b) computing weight factors that are to be applied to signals related to cellular telephone radio frequency signals having one of the predetermined frequencies;

(c) computing an angle of arrival for the radio frequency signals received having said one predetermined frequency, said weight factors being updated as the computed angle of arrival changes; and

(d) forming antenna array beams for the cellular telephone radio frequency signals using said weight factors,

the beams having higher signal to interference plus noise ratios in the direction of the computed angle of arrival.

8. A method of reducing co-channel interference at a cellular telephone base station by using an adaptive phased array of antennae to increase the signal to interference plus noise ratio on cellular telephone radio frequency signals, the method comprising the steps of:

(a) providing plural antennae for receiving and transmitting cellular telephone radio frequency signals on predetermined frequencies;

(b) computing an angle of arrival for the radio frequency signals received on said plural antennae on one of said predetermined frequencies;

(c) computing transmit weight factors that are updated as the computed angle of arrival changes;

(d) splitting signals related to the cellular telephone radio frequency signals that are to be transmitted from said plural antennae on said one predetermined frequency;

(e) multiplying said transmit weight factors times signals related to the cellular telephone radio frequency signals that are to be transmitted from said plural antennae to modify the gain and phase thereof; and

(f) combining the outputs from all of said multipliers for said one predetermined frequency to form antenna array beams having higher signal to interference plus noise ratios in the direction of the computed angle of arrival.

9. A cellular telephone base station that reduces co-channel interference by using an adaptive phased array of

antennae to increase the signal to interference plus noise ratio on cellular telephone radio frequency signals, the base station comprising:

(a) plural antennae for cellular telephone radio frequency signals having predetermined frequencies;

(b) a weight generator for computing weight factors that are to be applied to signals related to cellular telephone radio frequency signals having one of the predetermined frequencies, and for computing an angle of arrival for the radio frequency signals received having said one predetermined frequency, said weight factors being updated as the computed angle of arrival changes; and

(c) a processor for forming antenna array beams for the cellular telephone radio frequency signals using said weight factors, the beams having higher signal to interference plus noise ratios in the direction of the computed angle of arrival.

10. The base station as defined in Claim 9 wherein said weight factors are applied to signals related to received cellular telephone radio frequency signals.

11. The base station as defined in Claim 9 wherein said weight factors are applied to signals related to transmitted cellular telephone radio frequency signals.

12. The base station as defined in Claim 9 wherein said weight factors are applied to signals related to both received and transmitted cellular telephone radio frequency signals.

13. The base station as defined in Claim 9 wherein said weight factors are applied to one of radio frequency,

intermediate frequency and baseband signals.

14. A cellular telephone base station that reduces co-channel interference by using an adaptive phased array of antennae to increase the signal to interference plus noise ratio on cellular telephone radio frequency signals, the base station comprising:

(a) plural antennae for receiving cellular telephone radio frequency signals having predetermined frequencies;

(b) plural front end processors for forming the receive inphase and quadrature components of signals related to radio frequency cellular telephone signals received on one of said predetermined frequencies;

(c) a weight generator for using said receive inphase and quadrature components to compute receive weight factors, and for computing an angle of arrival for the radio frequency signals received on said one predetermined frequency, said receive weight factors being updated as the computed angle of arrival changes;

(d) plural multipliers for multiplying the receive weight factors times the receive inphase and quadrature components to modify the gain and phase thereof; and

(e) plural beamsummers for combining the outputs from all of said plural multipliers for said one predetermined frequency to form antenna array beams having higher signal to interference plus noise ratios in the direction of the computed angle of arrival.

15. The base station as defined in Claim 14 wherein said weight generator also computes transmit weight factors

that are to be applied to signals related to cellular telephone radio frequency signals that are to be transmitted from said plural antennae on said one predetermined frequency, said transmit weight factors being updated as said computed angle of arrival changes.

16. The base station as defined in Claim 15 further comprising:

plural beamsplitters for splitting signals related to the cellular telephone radio frequency signals that are to be transmitted from said plural antennae on said one predetermined frequency into transmit inphase and quadrature components;

plural second multipliers for multiplying the transmit weight factors times the transmit inphase and quadrature components to modify the gain and phase thereof; and

plural second beamsummers for combining the outputs from all of said plural second multipliers for said one predetermined frequency to form antenna array beams having higher signal to interference plus noise ratios in the direction of the computed angle of arrival.

17. A cellular telephone base station that reduces co-channel interference by using an adaptive phased array of antennae to increase the signal to interference plus noise ratio on cellular telephone radio frequency signals, the base station comprising:

(a) plural antennae for receiving and transmitting cellular telephone radio frequency signals on predetermined frequencies;

(b) a weight generator for computing an angle of arrival for the radio frequency signals received on said plural antennae on one of said predetermined frequencies, and for computing transmit weight factors that are updated as the computed angle of arrival changes;

(c) plural beamsplitters for splitting signals related to the cellular telephone radio frequency signals that are to be transmitted from said plural antennae on said one predetermined frequency;

(d) plural multipliers for multiplying said transmit weight factors times signals related to the cellular telephone radio frequency signals that are to be transmitted from said plural antennae to modify the gain and phase thereof; and

(e) plural beamsummers for combining the outputs from all of said multipliers for said one predetermined frequency to form antenna array beams having higher signal to interference plus noise ratios in the direction of the computed angle of arrival.

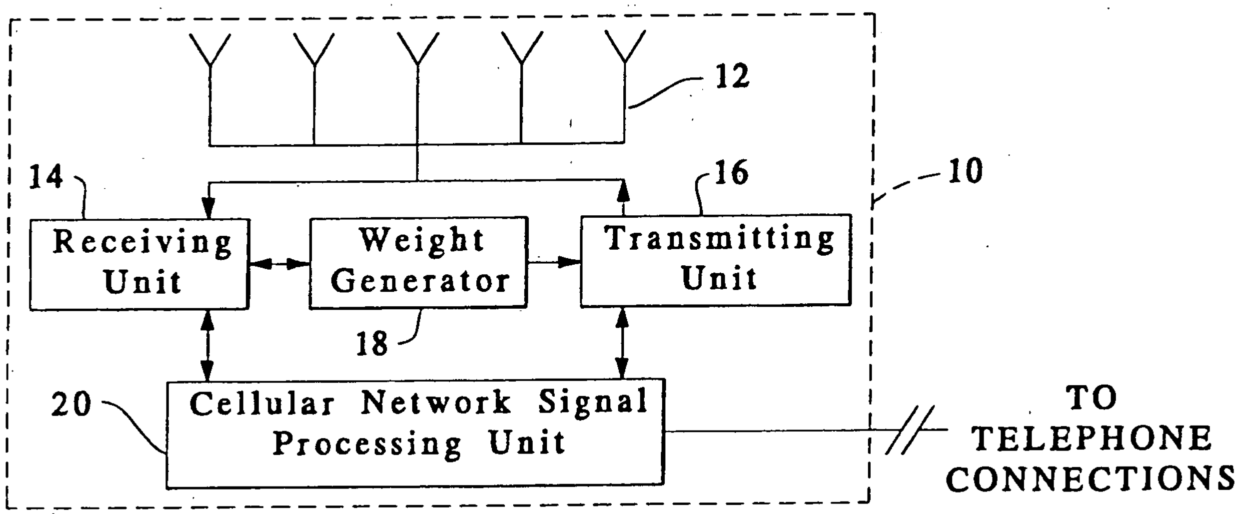
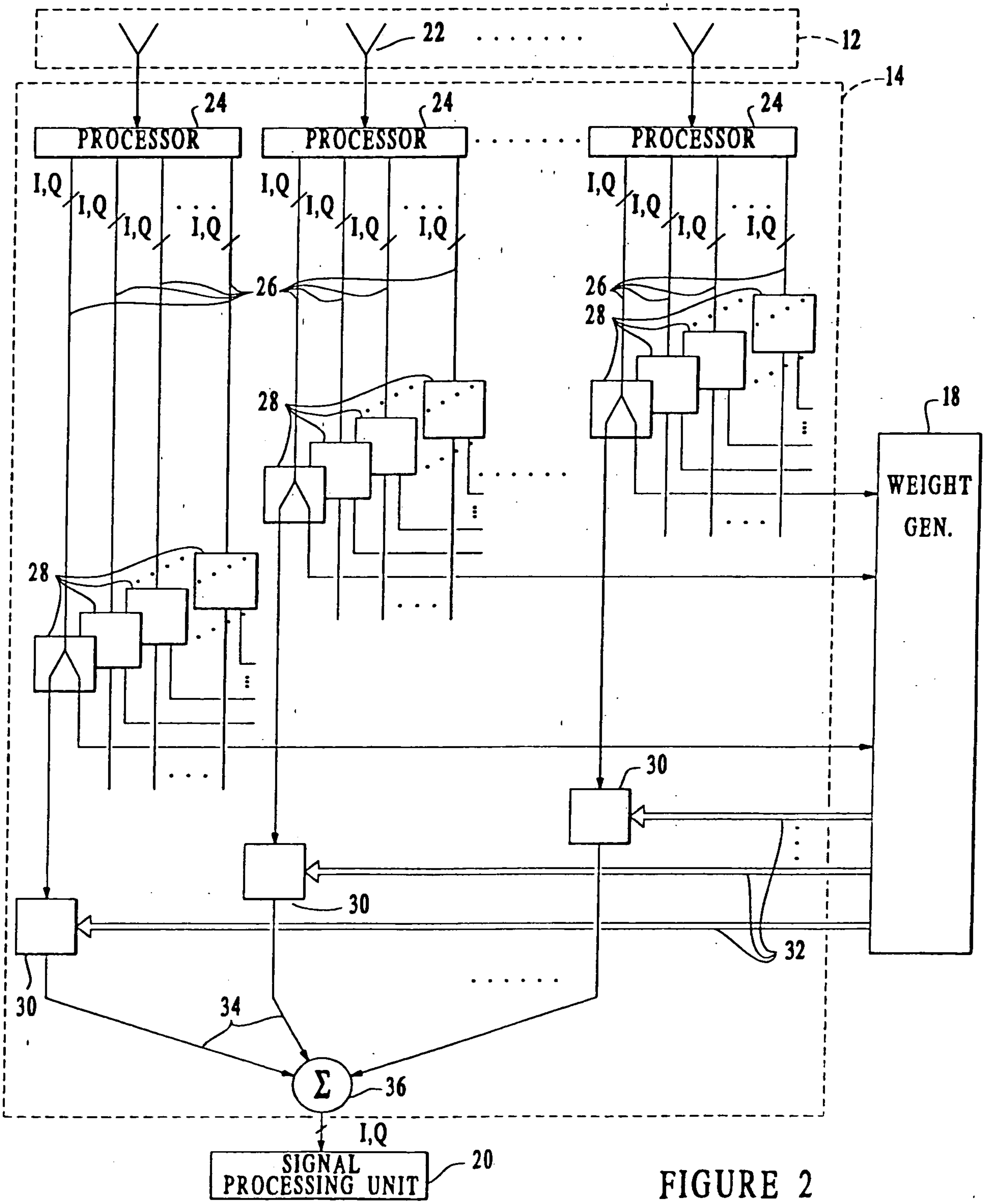

12
14
16
10
Receiving Unit
Weight Generator
Transmitting Unit
18
20
Cellular Network Signal Processing Unit
TO TELEPHONE CONNECTIONS

FIGURE 1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12
14
24
PROCESSOR
PROCESSOR
PROCESSOR
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28
18
WEIGHT GEN.
30
32
34
36
Σ
SIGNAL PROCESSING UNIT
20

FIGURE 2

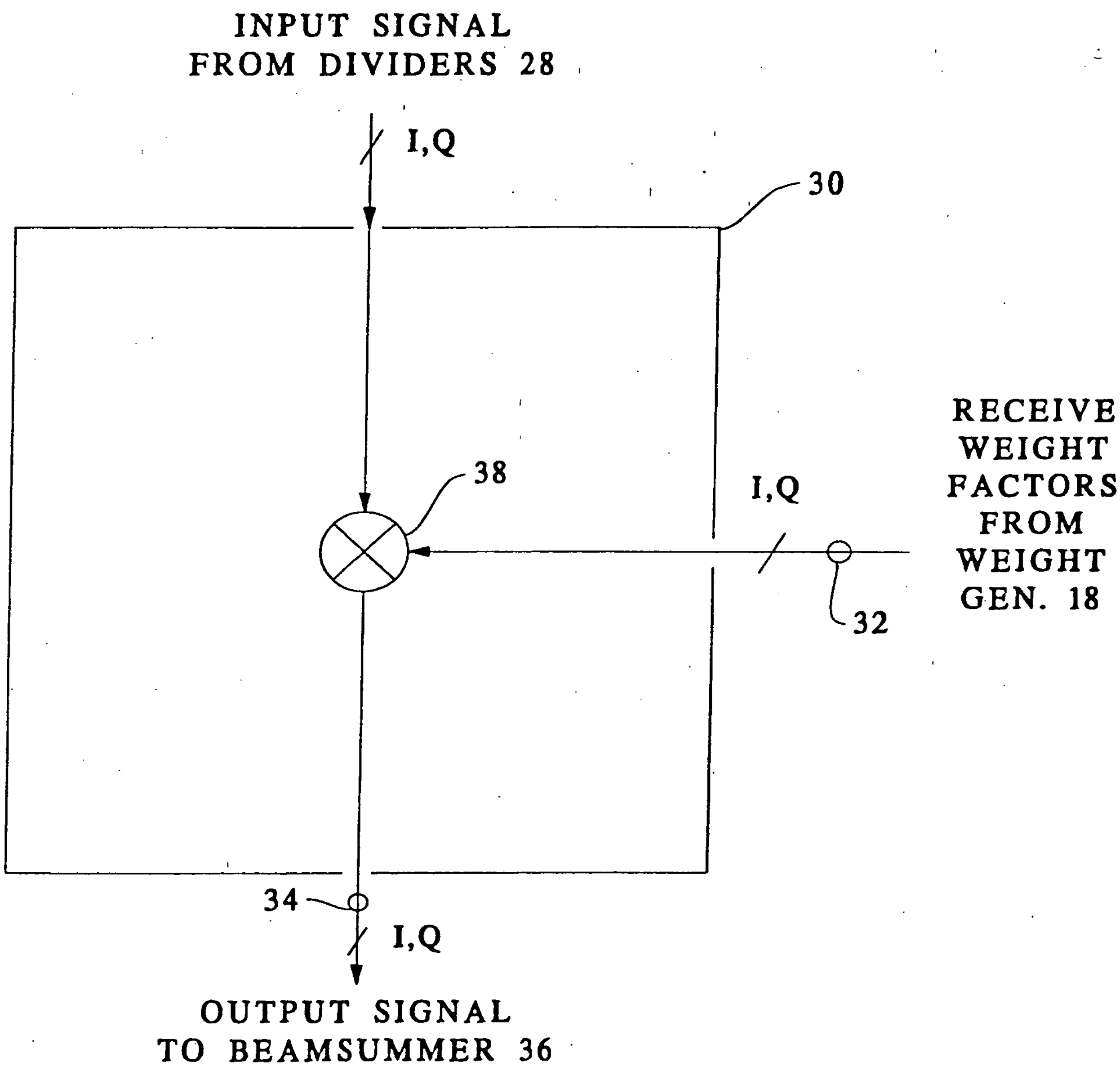
INPUT SIGNAL
FROM DIVIDERS 28
I,Q
30
38
I,Q
RECEIVE
WEIGHT
FACTORS
FROM
WEIGHT
GEN. 18
32
34
I,Q
OUTPUT SIGNAL
TO BEAMSUMMER 36

FIGURE 3

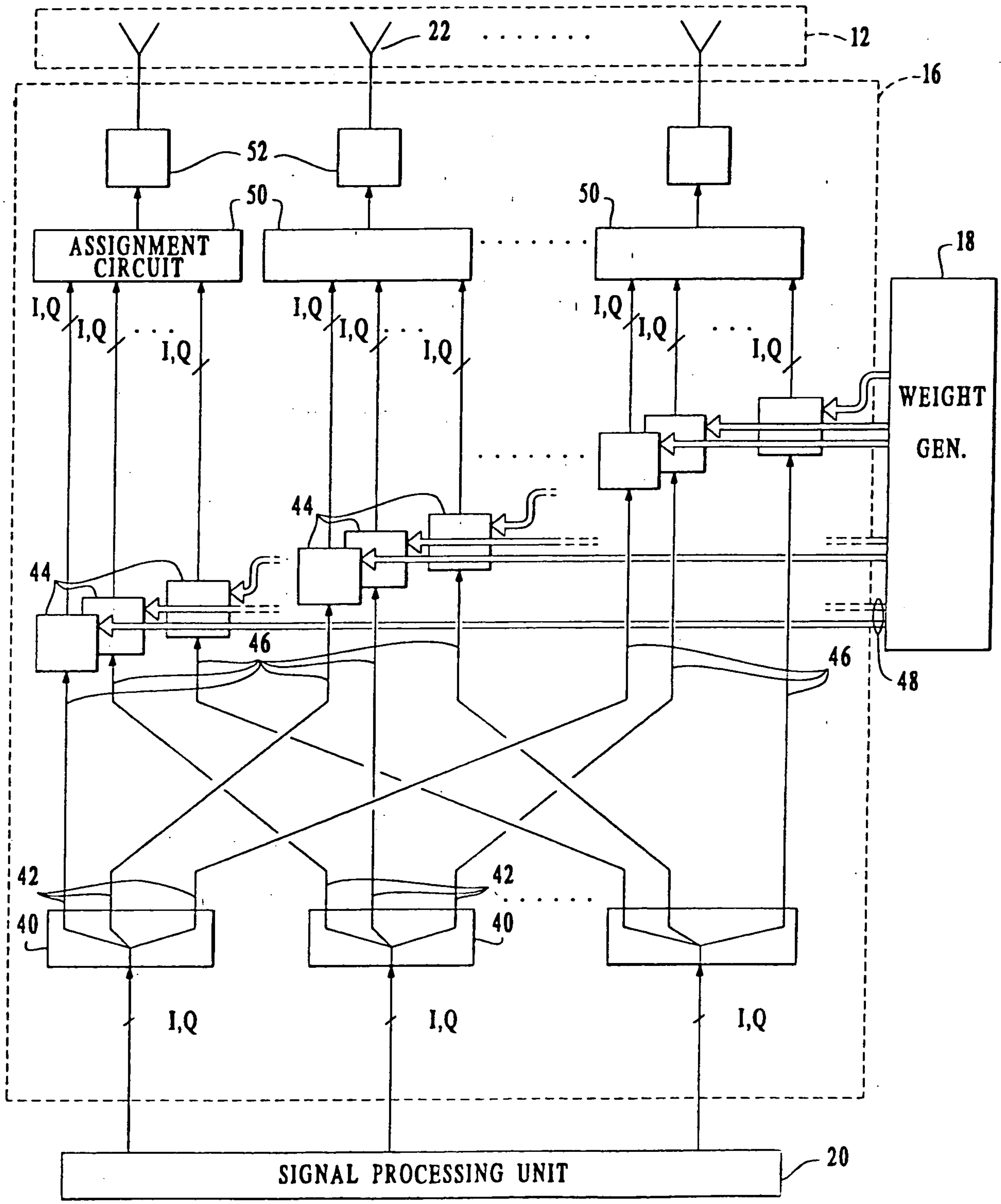
22
12
16
52
50
ASSIGNMENT CIRCUIT
50
18
I,Q
I,Q
I,Q
WEIGHT GEN.
44
44
46
46
48
42
42
40
40
I,Q
I,Q
I,Q
SIGNAL PROCESSING UNIT
20

FIGURE 4

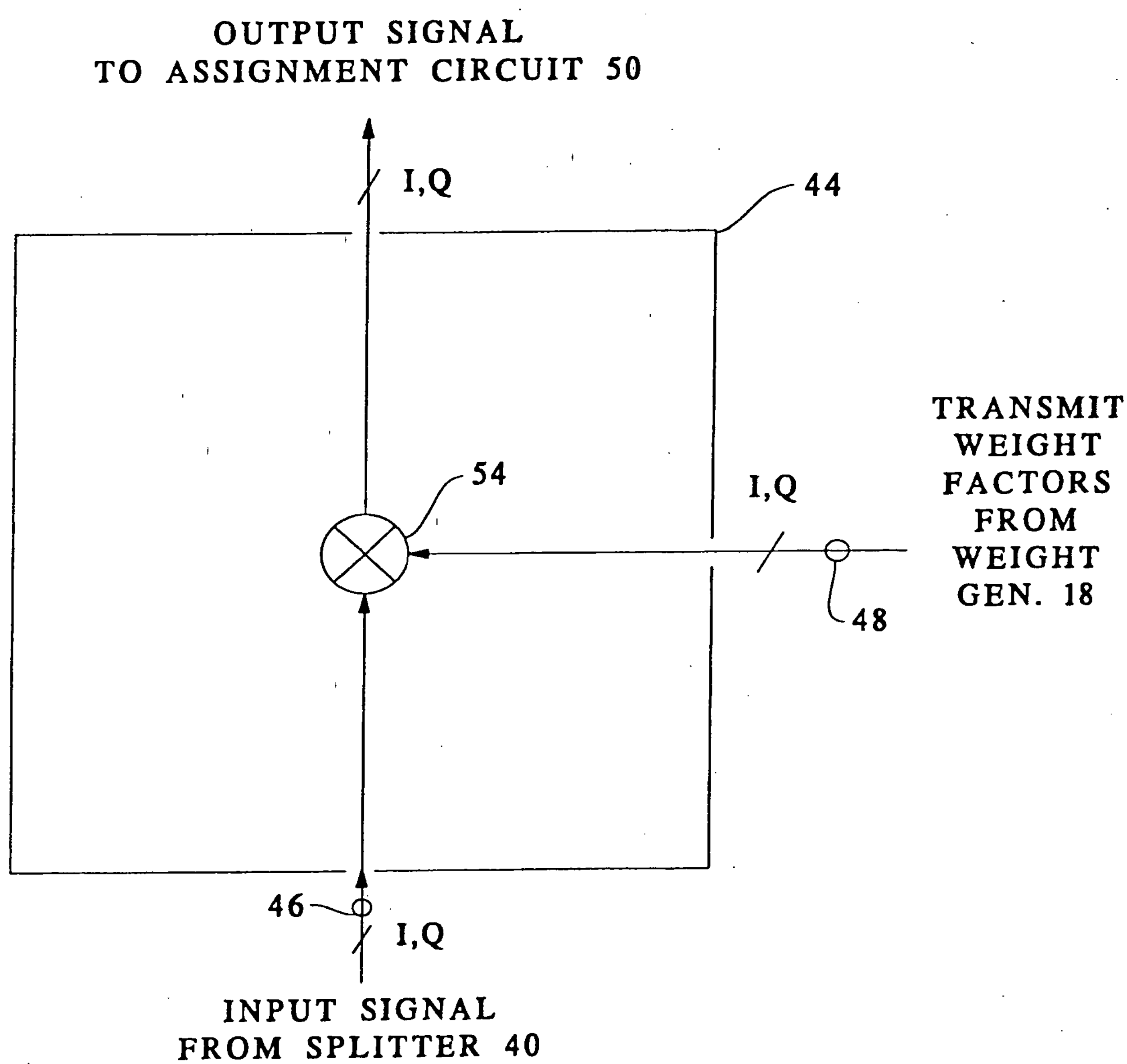
OUTPUT SIGNAL
TO ASSIGNMENT CIRCUIT 50
I,Q
44
54
I,Q
TRANSMIT
WEIGHT
FACTORS
FROM
WEIGHT
GEN. 18
48
46
I,Q
INPUT SIGNAL
FROM SPLITTER 40

FIGURE 5

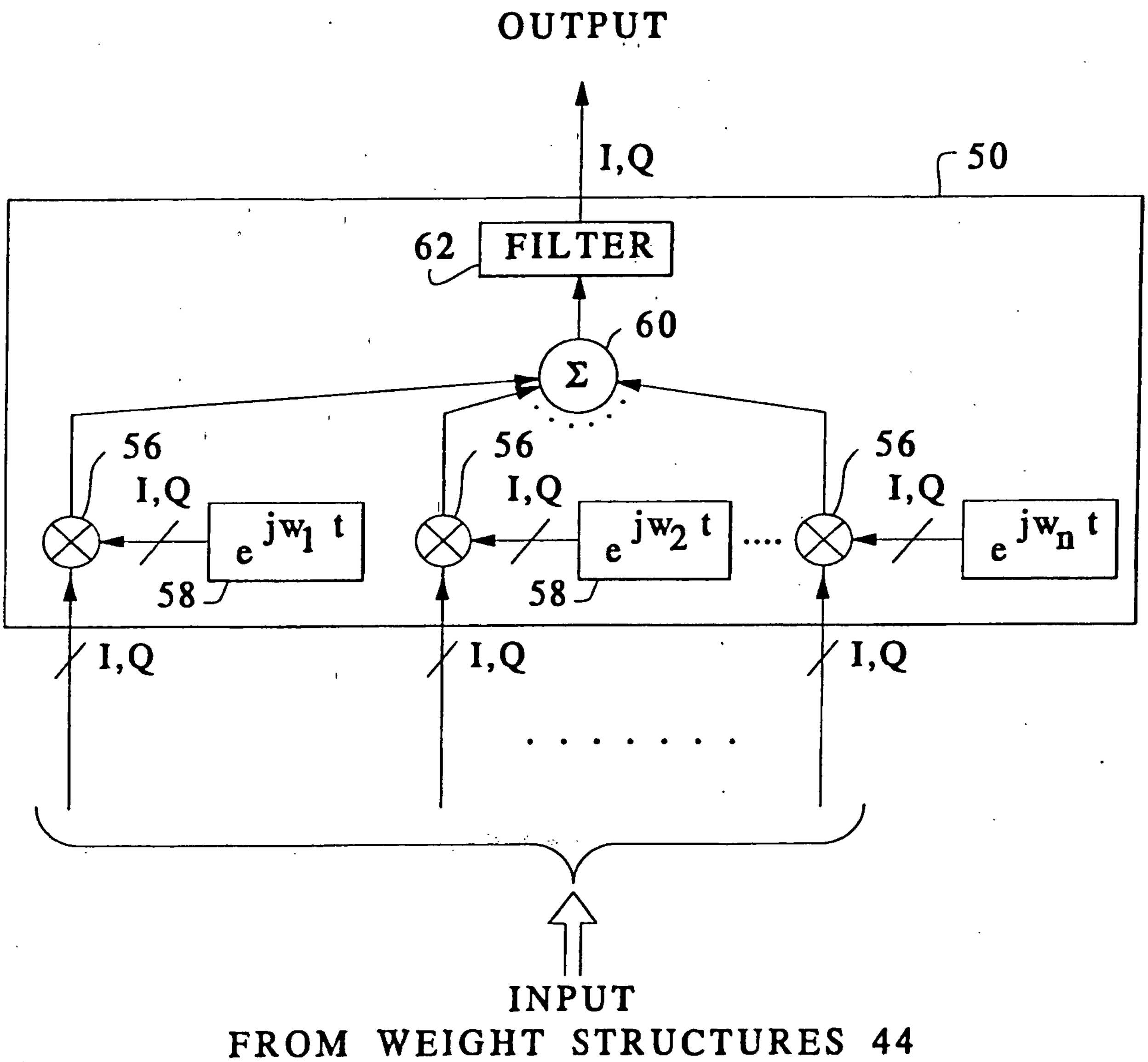
OUTPUT
I,Q
50
62
FILTER
60
Σ
56
I,Q
$e^{jw_1 t}$
58
56
I,Q
$e^{jw_2 t}$
58
56
I,Q
$e^{jw_n t}$
I,Q
I,Q
I,Q
INPUT
FROM WEIGHT STRUCTURES 44

FIGURE 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/09611

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :HO4B 01/10
US CL :455/272
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 455/272,33.1, 33.3, 63, 101, 275.1, 276.1, 277.1, 277.2, 283; 342/368, 371, 372, 373, 376, 377; 375/1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS
search terms: cellular, antenna, array, direction, base station

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,E ----- Y,E	US, A, 5,260,968 (Gardner et al) 09 November 1993, col 5, lines 6-15, figures 4,6.	2,9-13 ----------- 1,3-8,14-17

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be part of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 16 December 1993	Date of mailing of the international search report 04 FEB 1994
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. NOT APPLICABLE	Authorized officer PHILIP J. SOBUTKA Telephone No. (703) 305-4825

Form PCT/ISA/210 (second sheet)(July 1992)*